THE

CLIMATE OF THE EARTH

PAST AND PRESENT

CAPT. R. A. SARGEAUNT

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CLIMATE OF THE EARTH

'It goeth forth from the uttermost part of the heaven, and runneth about unto the end of it again: and there is nothing hid from the heat thereof'— PSALM xix.

NOTES

ON THE

CLIMATE OF THE EARTH

PAST AND PRESENT

BY

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PREFACE.

RATHER more than two years ago, when reading a standard work on astronomy, I was strongly impressed with the idea that the effect of the precession of the equinoxes on the climate of the earth had been generally very much underrated. Having, however, little leisure for the study of this subject, I was unable for some time to come to any conclusion; but the point was kept in view, and as opportunity occurred I perused such works as were considered likely to elucidate the matter, either directly or indirectly, and have drawn certain inferences therefrom, at the same time noting down what appeared of most importance. From these notes the following chapters have been compiled.

Although I have endeavoured to arrange the notes in as consecutive an order, and render them as readable, as possible, I fear that they will appear somewhat disconnected, and had I time at my disposal I would treat the subject in a manner more befitting its importance and interest. Works by the following authors have been consulted, viz., Dana, Ansted, Lyell, Lubbock, Guillemin, Murchison, Guyot, Tyndall, Johnston, Herschel, and others, and quotations from most of these will be found in the sequel.

In the plates representing the globe, the sphere has been projected, or rather developed, in the following manner. A right line has first been drawn on a given scale equal to the meridian at Greenwich, and this has been bisected by another right line equal in length to the equatorial circumference of the globe. The lengths of several parallels of latitude have been calculated, and these have been drawn parallel to the equatorial line in their re-

spective positions, and these parallels have been subdivided into equal portions for longitude, the points thus ascertained being joined by curves of varying curvature to represent the meridians of longitude. It is believed that this system of development gives as little distortion as practicable, the distances measured due east and west being absolutely true, and the north and south distances being appreciably exaggerated only towards the outside of the figure. The great objection to Mercator's projection is that the surface of the globe at the extreme north and south is infinitely distorted, and the figure does not present to the eye anything approaching a true idea of the relative sizes of the continents, islands, and seas. This objection is considerably mitigated in the system here adopted.

R. A. S.

June 21, 1875.

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CHAPTER I.

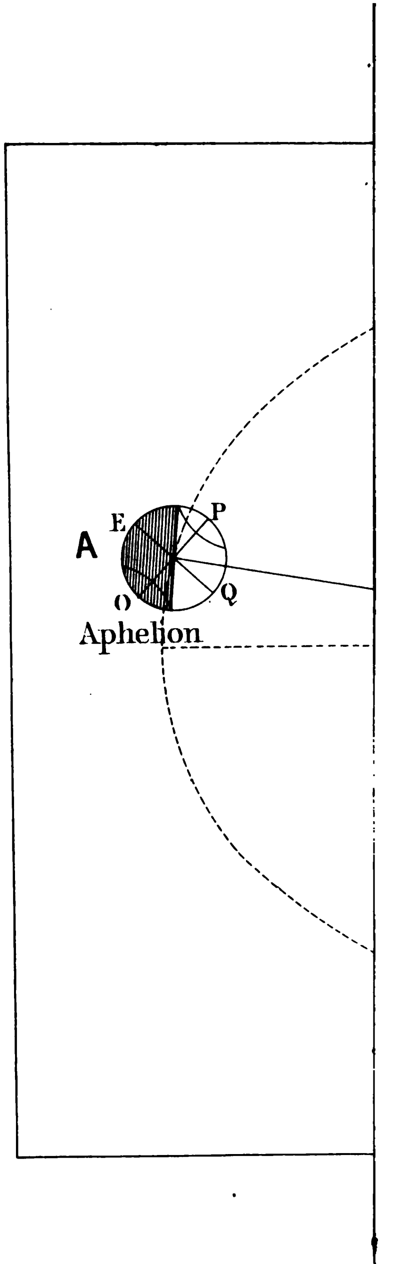
INTRODUCTION—ASTRONOMICAL POSITION OF THE EARTH, AND ITS SEASONS.

NOTWITHSTANDING that the earth occupies in the solar system a position astronomically inferior, it is to man of all bodies of the universe the most important; for on its surface he lives, moves, and has his being. Of the planets revolving round the sun the earth is the fifth in magnitude, being smaller than Jupiter, Saturn, Uranus, and Neptune; as regards satellites, it is less liberally furnished than Jupiter, Saturn, and Uranus; compared with the sun its magnitude is as 1 to 1,400,000. The sun, too, although apparently the largest of the heavenly bodies, is infinitely smaller than many of the fixed

stars, which occupy the space beyond the solar region in countless numbers, each of which is the sun-centre of its own universe.

The human mind is incapable of grasping the immensity of space occupied by this heavenly host. What an insignificant speck, then, is this earth among such a vast assemblage of mighty bodies! Yet, although comparatively insignificant, a globe of 259,800,000,000 cubic miles steadily revolving round the sun, accompanied by its satellite, and rotating with an even motion on its own axis, must to the human mind be stately and magnificent.

These motions of rotation and revolution are to man of the greatest importance. By the former his time is divided into days and nights, periods of work and rest, and by the latter into seasons; a complete revolution, speaking generally, forming one year. The actual time of rotation is about 23 hours 56 minutes, forming a sidereal day; the solar day is four minutes longer. This difference of four minutes is due to the earth's passage round the sun; for, as the earth will have advanced in its orbit during the time of rotation, it is manifest that the plane of


A
E
P
Q
O
Aphelion

the meridian which was directly opposite the sun at, say, noon on one day will after a complete rotation be parallel to its former position at a distance of a sidereal day's journey of the earth; and in order, therefore, that this plane may pass through the sun's centre, it must be inclined to its former position, or in other words the motion must be continued beyond the complete rotation.

The time of the earth's revolution round the sun is in mean solar time 365 days, 6 hours, 9 minutes, and 10·75 seconds. During this period the earth traverses from west to east the whole of its elliptic orbit at an average rate of 68,000 miles an hour, with its axis inclined at an angle of 66° 32′ 42″, the sun being fixed at one of the foci of the ellipse. It is the inclination of the earth's axis to the plane of her annual path that causes the succession of seasons, spring, summer, autumn, and winter. This is readily seen by the help of the accompanying figure No. I., where S represents the sun, and A B C D the earth, P O the polar axis, P being the north and O the south pole, and E Q the terrestrial equator, whose plane is inclined to that of the eclip-

tic at an angle of 23° 27′ 18″, or, say, 23½ degrees. When the earth is at A the north pole P is turned towards the sun, and the south pole O is left in darkness; in this relative position the sun is at its greatest north declination, viz. 23½°, shining vertically on the parallel of that north latitude; and during each rotation the whole of the northern hemisphere will be illuminated. This is the commencement of the Summer, and this point in the earth's path is called the summer solstice, as apparently the sun ceases to travel north and as it were remains stationary for a time before starting on its return journey southwards. Now suppose the earth to have completed one-fourth of its annual revolution and to have arrived at B, with its axis still parallel to its former position, or, as it is generally expressed, with its axis remaining parallel to itself. In this position neither pole is turned away from or towards the sun, and the solar rays will strike vertically on the equator, and during a complete rotation all parts of the earth's surface will be illuminated, the northern and southern hemispheres receiving equal shares of light and heat. This point is called the Autumnal

equinox, as the days and nights are then equal over the whole globe. Next suppose the earth placed as at C, having made half a revolution round the sun, then it is evident that the order of things in the first position will be reversed: the south pole will be turned towards the sun, whose declination will be $23\frac{1}{2}°$ south; Winter now commences, and the point occupied is called the winter solstice. At D is the Spring equinox, which is similar to the autumnal equinox in the relative arrangement, the only difference being that for the northern hemisphere the days begin to shorten and the nights to lengthen from the latter, whereas from the former the length of the days commences to increase and that of the nights to decrease.

Thus the year is divided into seasons dependent on the apparent obliquity of the sun's path through the heavens causing variations in the angle at which the solar rays fall upon the earth, and making the days sometimes shorter and sometimes longer than the nights. During the spring and the summer—that is, when the sun's declination is north—the sun remains above the horizon of the northern hemisphere longer than in the other two seasons, the

length of the day increasing from the vernal equinox up to the summer solstice, when it attains its maximum. This lengthened period of sunshine, assisted by the more direct incidence of the rays, is the chief cause of the greater warmth of Summer.

The earth which thus makes its annual tour round the sun is in shape an oblate spheroid, the equatorial being 27 miles in excess of the polar diameter. The figures are :—

Equatorial diameter	7926·6	miles
Polar "	7899·6	"
Difference	27	"

The equatorial circumference is in round numbers 25,000 miles, the mass of the body is 6,069,000,000,000,000,000,000 tons, and the volume 259,800,000,000 cubic miles. The surface of the globe divided into land and water gives approximately 52,000,000 square miles to the former and 144,712,850 square miles to the latter. The land area is distributed as follows :—

	Sq. miles.		Sq. miles.
Europe . .	3,800,000	Nth. America	8,500,000
Asia . . .	17,500,000	Sth. America	6,500,000
Africa . .	11,500,000	Oceania . .	4,000,000

'Inhospitable wastes, as the great sandy deserts of Africa, Asia, America, and Australia, with the cold icy tracts of the polar regions, and other barren grounds, occupy more than one-fourth of the entire land surface. Forests more or less dense, and most prominent in intertropical latitudes, cover a somewhat less area. But taken together, the extent of deserts and woody country is equal to more than one-half of the area of the superficial soil. The remainder consists chiefly of grassy plains, steppes or prairies, only a very small portion of which has been reclaimed from the hand of nature by cultivation, and occupied by permanent settlements of the human race.'[1]

[1] Milner's 'Gallery of Geography.'

CHAPTER II.

THE VARYING DISTANCE OF THE EARTH FROM THE SUN—THE PRECESSION OF THE EQUINOXES.

IN Sir John Herschel's 'Outlines of Astronomy,' clause 368, it is stated 'that equal amounts of heat are received from the sun in passing over equal angles round it, in whatever part of the ellipse these angles may be situated.' And again, in the same clause: 'Were it not for this the excentricity of the orbit would materially influence the transition of seasons. The fluctuation of distance amounts to nearly $\frac{1}{30}$ of its mean quality, and consequently, the fluctuation in the sun's direct heating power to double this, or $\frac{1}{15}$ of the whole.' And in the next clause, No. 369: 'This does not prevent, however, the direct impression of the solar heat in the height of summer—the glow and ardour of his rays, under a perfectly clear sky, at noon, and under equal circumstances

of exposure—from being very materially greater in the southern hemisphere than in the northern. One-fifteenth is too considerable a fraction of the whole intensity of sunshine not to aggravate in a serious degree the sufferings of those who are exposed to it in thirsty deserts, without shelter. The accounts of these sufferings in the interior of Australia, for instance, are of the most frightful kind, and would seem far to exceed what have ever been undergone by travellers in the northern deserts of Africa.'

Now, the difference in the distance of the earth from the sun here referred to is not constant for the same season throughout all ages, but is constantly varying; and it is proposed to consider what physical effects may be expected to arise from this constant change, and also to investigate some other sources of the unequal distribution of solar power, and the consequent results. It may be as well, in the first instance, to recall to mind in as brief a manner as possible the origin of the difference of the sun's distance from the earth, and of its varied intensity at the earth's surface.

In figure No. I., page 3, as before, S represents the sun, and B and D the earth, at the autumnal and vernal equinox, and A and B at the summer and winter solstice: P and O are the north and south terrestrial poles respectively. In the figure the ellipticity of the orbit is considerably exaggerated, as otherwise it would be imperceptible in a diagram. Now it is manifest from the figure that during the half-year in which the sun's declination is south—that is, whilst the earth is passing from B to D—the distance between the two bodies is less than during the remaining portion of the year, and it might at first sight appear that this fact alone would in a great measure cause the total amount of heat received on the earth's surface during one half-year[1] to exceed that distributed during the other half-year;[2] but this is not the case, for the difference of distance is approximately compensated for by a greater rapidity of motion, and thereby a diminution in the time of exposure. The intensity of the heat varies as the square of the distance, and the velocity of the globe in its

[1] More correctly one half-revolution.

path varies as the square of the radius; or, to express this algebraically,

$$\text{Velocity at A : Velocity at B} :: BS^2 : AS^2.$$

And if the amount of heat, so to speak, afforded to the earth during its passage through a given angular distance, at A, be represented by H, and *h* be the same for an equal angular distance at B; then

$$H \times \text{Vel. at A} : h \times \text{Vel. at B} :: AS^2 : BS^2$$

$$\text{Therefore } \frac{H}{h} = 1$$

$$\text{or } H = h.$$

The same applies to any portion or the whole of the arcs D A B and B C D. This means that every year the total quantity of heat supplied to each hemisphere is equal, although its intensity greatly varies, both the summer heat and the winter cold being much greater in degree in the south than in the north. This state of things is, however, gradually and surely undergoing a change, for each succeeding year the summer and winter seasons approach somewhat towards a common length of duration. This change is certainly very slow, and takes about 25,870 years for its completion. The

cause of this, which is technically called the 'precession of the equinoxes,' is due to the gradual change in the position of the pole, and consequently in that of the equinoctial.

As the precession of the equinoxes will be referred to again further on, the phenomena will be explained a little more fully. In explanations of this nature—that is, relating to the movement of bodies in space—it is most convenient to have recourse to some practical illustration with the assistance of a model. This may be done in the present instance by taking an apple, orange, or other spherical body, and passing a spindle through its centre to represent the axis, and marking a line round the surface to take the place of the terrestrial equator. This forms the miniature earth. The earth's orbit may be replaced by the circumference of a dish or table plate, or the edge of a circular or oval table. Now if the sphere be so applied to the rim of the plate that the equatorial line is in contact therewith, and its axis inclined at an angle of 66° 32′ 42″ with the plane thereof, it will represent the position of the earth at one of the

equinoxes; and if the sphere be moved round the plate, the axis being carefully kept parallel to its original position, the equatorial line will be found to break contact with the orbit, either falling below or above it in accordance with the direction to which the axis is inclined, but will again come in contact after completing half the circuit, and again when the whole circuit is completed, for then it will be in exactly the same position as at starting. But suppose that instead of the axis remaining parallel to itself it be somewhat displaced, without any change in the angle of inclination to the plane of the orbit, and this displacement be made at once; then it will be seen that the equator is no longer in contact with the plate's edge, and that the sphere must be carried back a certain distance in order that it may be so. Now had this change in the direction of the axis been gradually going on during its circuit, it is apparent that the contact of equator and orbit would have taken place before the half and again before the entire circumference had been traversed. Thus the equinox from which the earth started would have occurred before its

return to the same point. This is what actually takes place: the axis of the globe describes a cone in a period of about 25,868 years, and thus during this long interval the equinoxes, both vernal and autumnal, occur at so many points on the orbit.

Another important effect of this conical movement is the constant change of the pole star; this, however, does not directly bear on the present subject.

It is clear from the foregoing that at some future date the equinoctial points will coincide with the extremities of the axis major of ecliptic, and then the duration of the spring and summer will be exactly equal to that of autumn and winter, and, cæteris paribus, the intensity of the heat and cold will be also equal in each hemisphere, for the mean distance of the sun from the earth during its stay on either side of the equator will be the same.

The effect of this precession as experienced in the varying power of the sun's rays is evidently dependent on the elliptic form of the earth's path, but this form is constantly changing; at one time ap-

proaching nearly to a circle, and at another becoming considerably elongated. This variation, which is only appreciable through large periods of time, is caused by planetary perturbation. The excentricity is now small, *i.e.* the orbit is nearly a circle, the distance from the solar focus varying between the limits of about 91 and 93¼ millions of miles, the mean being 91,678,000 miles; but about 200,000 years ago this difference exceeded ten millions of miles, and then the effect produced must have been far greater than at the present day. This subject of the changes in excentricity will be entered into more fully in a subsequent chapter.

It has been stated above that the great cycle of the precession of the equinoxes would be complete in 25,868 years; this period is, however, somewhat shortened by the revolution of the line of the apsides, and becomes approximately 21,000 years.

CHAPTER III.

CLIMATOLOGY.

IN the last chapter endeavours were made to explain one of the causes of the sensible difference of summer heat, as experienced in the northern and southern hemispheres respectively. Besides the variable distance of the earth from the universal light and heat giver, there are many causes, some of which are minor and local, at work, whereby great diversity of climate is experienced, even with localities on the same side of the equator and in the same latitude.

The first or prime origin, however, of the various climates experienced on the surface of the globe is the same as that which causes the seasons of spring, summer, winter, and autumn, viz., the passage of the earth round the source of heat with an axis inclined at an angle to the plane of the orbit. In fact, the etymological sense of the word

climate refers to this cause alone, for it is derived from the Greek κλίμα, from κλίνω I incline, that is to say, it is dependent on the inclination of the solar rays to the horizontal plane. In the general and ordinary acceptance of the term, its meaning embraces all modifications of the atmosphere by which the human organs are sensibly affected. Although these modifications are in the main dependent on the direction in which the sun's rays reach the surface, and the consequent duration of the sun above or below the horizon, they are nevertheless considerably influenced by geographical position, altitude, and sundry meteorological causes.

The temperature, then, of any country being, for the most part, dependent on the power of the solar rays, which varies with the number and obliquity of such rays to the surface, will in consequence vary as the square of the cosine of the latitude when the sun is on the equator, and as the square of (the latitude $\pm$ sun's declination) for all positions of the sun, assuming that its distance is the same in all cases. This is easily explained by means of a diagram. In figure No. II. let P repre-

sent a particular spot on the earth's surface in latitude 30° north, the declination of the sun being 10° south. Then the solar ray R P will be parallel

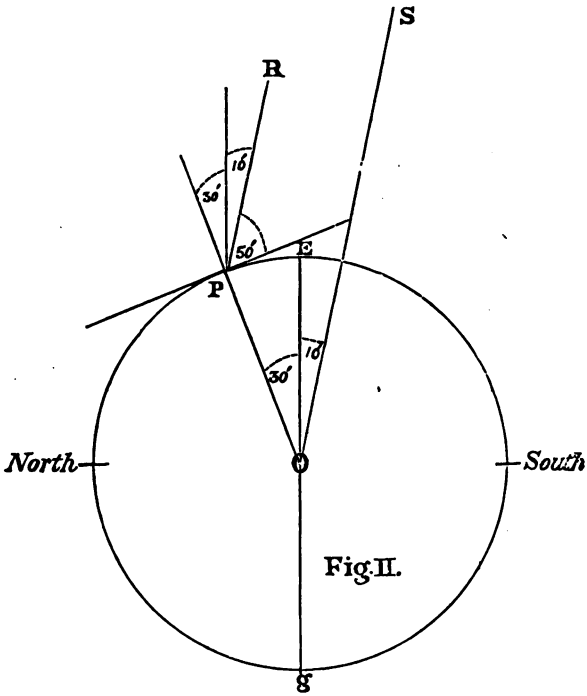


Fig. II.

to S O, or the ray which passes through the earth's centre, and will impinge on the spot P at an angle of 50°. The power of the ray being proportional

to the sine of the angle of incidence; if R represent its full direct force, the effect at P will be R sine 50° = R cosine 40° = R cosine (latitude + declination). Now as regards the number of rays falling on any given area, it is evident that this must vary inversely as the inclination of the plane at the particular spot to the ray's direction; and thus if NR be the number of rays falling on the given area when it is at right angles to their direction, then the number striking the same limited surface whose inclination is 50° as in figure, will be NR sine 50°, which as before becomes cosine (latitude + declination).

Had the sun's declination been north, or on the same side of the equator as the locality in question. the plus sign would obviously have become negative, and hence, as previously stated, the temperature theoretically varies as the square of the cosine of (latitude ± declination). It must be understood that this law only applies to areas of some extent, in which the surface undulations are compensatory; for doubtless many slopes, even in England, receive individually the sun's rays in summer as perpendi-

cularly as the plains within the tropics, yet these do not experience a tropical climate.

Although theory may be perfectly correct as such, there are always found in practice many disturbing elements which must not be neglected, and to omit these from the present question would be as unreasonable as to omit the laws of friction from the study of practical mechanics.

It may be remarked that no account has been taken of the varying thickness of the atmosphere through which the solar rays have to pass. If the radius of the earth be 4,000 miles, and the depth of air 50 miles, then at the time of the equinoxes the regions about the poles will have upwards of 634 miles of atmospheric air imposed between them and the sun, or nearly thirteen times as much as those parts immediately bordering on the equator. As air, however, when dry, allows heat to pass through it, without absorbing more than a very small amount, the effect of this difference is not so large as might be expected. Moreover, the thickness of this interposed atmosphere rapidly decreases on proceeding from the pole towards the equator; for a

latitude of 61° it is about 97 miles, for $48\frac{1}{2}$° it is $66\frac{3}{4}$ miles, and for 30° it is not more than 58 miles, or not quite one-sixth more than at the equator.

Then there is the effect of altitude. This is apparent to the casual observer, from the snowy covering of many elevated mountains, and has been confirmed by a great number of experiments, from which a law whereby the decrease of temperature takes place has been determined. The main cause of a lower temperature being found at high elevations is the greater rarefaction of the atmosphere and the consequent smaller absorption of the heating rays. The effect, however, is more or less influenced by radiation from the surface, and atmospheric currents, and these again are subject to modifications from various causes, such as the nature of the surface of the surrounding country, both as regards its covering and configuration.

The atmosphere being formed of an excessively elastic body, naturally becomes more and more dense as the superincumbent mass is increased, until the strata which immediately envelope the earth become most suited for the wants of animal

and vegetable life. It is impossible to fix any very exact thickness for the earth's atmosphere, as no line can be drawn exactly circumscribing its limits, for as these are approached the exhaustion of the air becomes so great and so rapidly increases, that from its great tenuity it becomes as it were imperceptible. It is generally considered, however, that the atmospheric air does not extend to a greater height than 45 or 50 miles above sea level.

As the tenuity of the atmosphere increases, so is the radiation of heat into space more readily admitted, and thus the earth and other solid bodies do not so readily retain the effect of the sun's rays, which are in a great measure reflected, the result caused being far less than would be the case were the body impinged on surrounded by a covering of greater density.

That atmospheric currents should have a decided effect on the climate is easily understood; there are few in England who are not acquainted with the chilliness of the north-east wind, which has given rise to the common saying—

> 'When the wind is in the east
> It's good for neither man nor beast.'

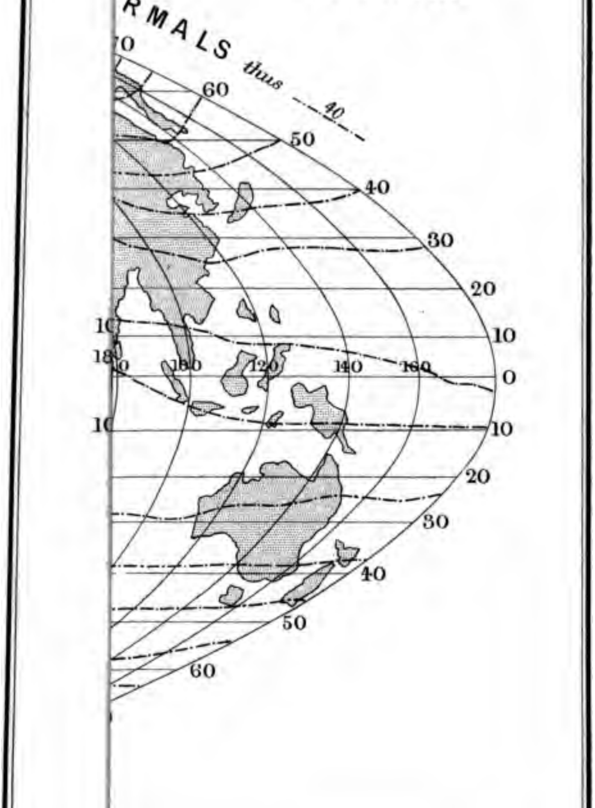
In fact, the movements of the air conspire to form an important part of the climate. For instance, the well-known Sirocco coming from the Great Sahara strikes the southern slopes of the Alps with its hot breath, and, warming them, causes the snow line to take up a more elevated position than it otherwise would occupy. The prevailing wind of any locality is greatly affected by the position of such locality with regard to other land, especially as regards its elevation, also by the vicinity or otherwise of any great ocean or large desert. Thus the wind coming from a heated sandy desert or sun-burnt plain is more or less scorching, that coming from a large ocean in the warm latitudes is temperate and balmy, and that from snow-clad mountains or ice-bound seas is cold and cutting.

Configuration of surface, irrespective of the elevation of the spot in question, is, perhaps, the most important of all minor causes which conspire together to diversify the climates of the different localities on the face of the globe. The relative proportion of land and water, the currents of the neighbouring ocean, the inclination and general aspect of the site, the ruling directions of the neighbouring valleys and

watersheds, the elevation and bearing of adjacent mountains, and the general drainage of the ground, all, to some extent, have their influence on the climate.

A very important principle to be borne in mind is that the propinquity of an ocean temperates, and the propinquity of land intensifies the climate. That this is the case may be seen from a map of isothermal lines, such as published by Humboldt and Dove in 1848, figure No. III. Taking the northern of the two isotherms marked 80°, and tracing its course westward from the Pacific Ocean, it will be observed that as it approaches the continent of Asia it recedes from the equator until it reaches the twentieth degree of latitude, and again nearing open sea on the west coast of Africa it inclines towards the south under the influence of the Atlantic Ocean. Thus in tropical latitudes the continent increases, and the ocean moderates the heat. If the isotherm of 20° be taken, it will be found that the reverse takes place, *i.e.*, in high latitudes the continents intensify the cold, which is again moderated by the ocean.

FIG. III.



Stanford's Geog.l Estab.t 55, Charing Cross.

By following this point up a little further, the cause of the effect will be found to lie in the relative specific heats of water and of the solid portion of the earth's surface. The specific heat of water is about four times as great as that of rock, and consequently its temperature is not so rapidly increased by the solar rays ; and on the other hand, the water is much slower in parting with its heat than the surface of the land. It is owing to this temperating power of the sea that islands and sea coasts as a rule enjoy more moderate climates than localities situated in the interior of continents; for instance, the burning deserts in Central Africa and the excessive cold in Siberia. With the ocean climates the great evaporation from the sea acts as a moderator by producing an overcast sky, by which the solar heat of summer is rendered more temperate than it otherwise would be, and the radiation from the surface of the earth in winter is to an appreciable extent checked.

In order to point out that ocean currents play an important part in the ruling causes of climates, it is only necessary to refer to the so-called Gulf

Stream, which acts as a vehicle of heat, bringing it from the tropics towards the north, and producing a sensible effect even as far as Spitzbergen. As this current conveys heat towards the north, so others carry icebergs from the polar oceans to materially lower the temperature of the regions through which they pass, and to cause extreme cold wherever they collect in any number. Sir Charles Lyell writes: 'In Baffin's Bay, on the west coast of Greenland, where the temperature of the sea is not mitigated by the same cause, the glaciers stretch out from the shore, and furnish repeated crops of mountainous masses of ice which float off into the ocean. The number and dimensions of these bergs is prodigious. Captain Sir John Ross saw several of them together in Baffin's Bay aground in water 1,500 feet deep! Many of them are driven down into Hudson's Bay, and, accumulating there, diffuse excessive cold over the neighbouring continent; so that Captain Franklin reports that at the mouths of Hayes' River, which lies in the same latitude as the north of Prussia or the south of Scotland, ice is found everywhere in digging wells, in summer, at

the depth of four feet!' More on this subject of currents will be found in the next chapter.

That the general inclination of any tract of country considerably influences the climate appears evident on slight reflection; the surface of the ground receives the heating rays of the sun at an angle more or less inclined, it is more or less sheltered from the cold or hot winds. This is most noticeable on passing through the Mont Cenis tunnel at certain seasons of the year; the country at the northern extremity may be covered with snow, whereas on the southern side of the mountain it may be found clothed with verdure and rejoicing in the fertilising warmth of an Italian sun. In fact, in the short space of a few miles one may pass from the depths of winter to a glorious spring.

The neighbouring irregularities of surface, such as valleys and mountains, play their part in modifying the direction and temperature of the winds. The winds may be diverted from their course; positions to the leeward of mountain ranges may be entirely sheltered from prevailing cold currents of air, and only exposed to the more genial breezes.

or these effects may be partially obtained. There is, however, a more powerful property of mountains of any considerable elevation resulting from a more indirect and insidious cause, viz., the deprivation of a large portion of the moisture from the air which is condensed on the mountain side, the country immediately to leeward being thereby robbed of what would otherwise form a protecting screen of vapour; thus is allowed both a greater exposure to the sun's rays, and more rapid surface radiation, the extremes of temperature becoming more excessive.

This power of absorption and radiation of heat possessed by aqueous vapour is very remarkable, and is a most active agent in equalising temperature. Professor Tyndall has proved by numerous and most careful experiments that perfectly pure dry air allows, as it were, a free passage to heat, but that when mixed with a small quantity of vapour it opposes an obstacle to such passage, and exacts a considerable tribute. It is not only the visible vapour in nature that makes itself felt in this way, for even with a clear blue sky there is

sufficient moisture to exert a powerful effect. Although this vapour is no doubt beneficial in moderating the intensity of the solar rays, the great advantage of its presence appears to be derived from the manner in which it acts as a covering to retain the warmth received on the earth's surface after the withdrawal of the source of heat; for were the atmosphere deprived of its moisture, the temporary withdrawal of the sun from any region would be followed by quick and excessive refrigeration. This is partially experienced in all large deserts, where the superincumbent air is in general more dry than in other localities. A traveller in the Great Sahara writes:[1] 'We rose at four o'clock. It was a dark, cloudless, nipping-cold morning, and I was fain to substitute hair-glove for sponge-bath, especially as we were on allowance. By six o'clock the tents were struck, and we sent the camels in advance before dawn. The hoar-frost was thick on the shrubs.' Thus the radiation during the night had been sufficient to produce a frost in the

[1] 'The Great Sahara,' by H. B. Tristram, M.A., F.L.S., &c.

region where 'the soil is fire, and the wind is flame.'

It has already been mentioned that the decrease in temperature found at high altitudes is in a measure due to the more rapid radiation. As by far the greater portion of atmospheric vapour exists at a very low level, the lofty mountains are rapidly deprived of their heat, which, unimpeded, quickly vanishes into space.

CHAPTER IV.

GREAT VARIATIONS OF CLIMATE AT DIFFERENT AGES.

THE Geologist has undoubtedly proved that the earth has experienced in past ages most remarkable variations of climate; those regions which now enjoy what is called a temperate climate having been at one time in a great measure submerged beneath a glacial sea, and at another period having been sufficiently heated to support animals and plants of a nature only capable of existing, with the present state of things, in tropical countries.

Signs of the glacial epoch in the British Isles are unmistakable; such as the existence of erratic rocks, furrows, and striæ and moraines. Without recourse to glacial actions these cannot be satisfactorily explained. The species, also, of marine testacea found in the Norwich crag are clear evidences of a former climate colder than that now

experienced in England. Sir Charles Lyell, after describing the coralline and Norwich crag shells, goes on to say: 'The cold, which had gone on increasing since the time of the coralline to that of the Norwich crag, continued, though not perhaps without some oscillations of temperature, to become more and more severe after the accumulation of the Norwich crag, until it reached its maximum in what has been called the glacial epoch. The marine fauna of this last period contain, both in Ireland and Scotland, recent species of mollusca now living in Greenland and other seas far north of the areas where we find their remains in a fossil state.'

Going further south, may be seen most distinct ice marks on the Jura mountains, now entirely free from glaciers; there are, too, remains of extinct glaciers in Northern Italy. Also the prevalence of northern shells in the Sicilian seas indicates a climate considerably colder than at present. Moraines and other marks of glaciers exist in Syria, where now there is a mild climate.

Accumulative evidence of this nature derived

from the two independent sources, viz., inorganic matter and organic remains, may be heaped together until it becomes perfectly irresistible. But if this be not sufficient, a third proof of former cold, so to speak, was brought to notice by Professor Forbes. This is derived from the present distribution of animals and plants in mountainous regions, especially in high latitudes in Europe and North America. When the elevated parts of these regions were uninhabitable, owing to their covering of ice or snow, an arctic fauna and flora must have occupied the plains, and on the gradual increase of temperature these would by degrees ascend to the more lofty parts, so as to have a climate suited to their nature. 'The identity of species now found in isolated patches at or near the tops of so many widely separated mountains would have been inexplicable had not the geologist discovered that about the close of the Tertiary era there was a glacial epoch.' [1]

The organic and inorganic signs above mentioned occur in the Newer Pliocene and Post Pliocene

[1] Sir Charles Lyell.

geological formations. By going further back into the past, it is found that the white or coralline crag of Suffolk of the Older Pliocene strata contains testacea of a less northern character; and the Bovey Tracey lignites and clays of the Lower Miocene era furnish fossil plants of a subtropical nature; similar evidence is afforded by the corresponding beds in America. The Upper Miocene faluns of Touraine also yield subtropical testacea. Fossil plants, too, have been brought from Greenland, whose nature renders the previous existence of a mild climate necessary for their growth. Without entering further into the evidences afforded by geology, which may be found in all works on that subject, suffice it to say that it appears certain that the earth has experienced great oscillations of temperature. At one time the tropical warmth extended to the north of the British Isles, but a gradual cooling took place, and subsequently an arctic climate reached to the south of Europe. This again became considerably relaxed, and the present meteorological conditions of the earth's surface followed.

This being so, the questions naturally arise—

How can these climatic waves be accounted for? Does their cause or origin still exert its influence? Is our climate at the present time surely, though imperceptibly, undergoing a change? Is it becoming cooler or more warm? These latter questions would be easily answered if the first could be fully solved.

The following causes have been adduced as bearing on the subject:—

1. Variation in the intensity of solar radiation.
2. Difference in temperature of the various regions of space passed through.
3. Decreasing density and cloudiness of the atmosphere through a diminution of the proportion of carbonic acid and moisture.
4. Secular refrigeration of the globe.
5. Oceanic currents.
6. Variations in extent and elevation of land.
7. Alteration in the direction of the earth's axis.
8. The inequality of the seasons due to the precession of the equinoxes, and the varying excentricity of the earth's orbit.

No. 1. A great objection to the first theory is that it promulgates one unknown to explain another; it is purely hypothetical and unsupported by sufficient testimony to merit much consideration until it has been proved that all others admitting of investigation have failed. One adverse argument, however, may be mentioned. Professor Tyndall, in his 'Heat considered as a Mode of Motion,' says: 'Cold will not produce glaciers. You may have the bitterest north-east winds here in London throughout the winter, without a single flake of snow. Cold must have a fitting object to operate upon, and this object—the aqueous vapour of the air—is the direct product of heat. Let us put this glacier question in another form: the latent heat of aqueous vapour at the temperature of its production in the tropics is about 1,000° Fahr., for the latent heat grows larger as the temperature of evaporation descends. A pound of water thus vaporised at the equator, has absorbed one thousand times the quantity of heat which would raise a pound of the liquid one degree in temperature. . . . . It is perfectly manifest that by weakening

the sun's action, either through a defect of emission, or by the steeping of the entire solar system in a space of low temperature, we should be cutting off the glaciers at their source.'

No. 2. The second theory is, like the first, hypothetical, and also liable to the same objection. For the formation of glaciers it is necessary to have both heat and cold, that is, a great divergence of temperature over the earth's surface at the same time.

No. 3. The variation in the quantities of vapour and carbonic acid in the atmosphere, although probably exerting some influence on the climate, cannot be held to have produced more than an infinitesimal modification on the whole amount of change which has taken place. The increase in the power of the air to absorb and radiate heat by the admixture of aqueous vapour has already been noticed. The aqueous vapour may be replaced by carbonic acid gas with similar results. But the admission of these facts does not render the theory any more tenable; for, in the first place, it cannot be shown that the quantity of vapour and carbonic

acid in the air has ever varied to any appreciable extent, nor can any satisfactory reason be given why such a variation should have taken place, at least as regards the gas. The amount of vapour would no doubt diminish by an increase in the amount of land area, especially of large continents, but such a change would at the most be only partial and very limited in extent; and, in the second place, if a general decrease in the quantity of these bodies be admitted, their combined power could not cause a glacial epoch, for how would the snow and ice be formed without the aqueous vapour. As stated above, this would be cutting off the glaciers at their source. In looking, therefore, for the chief cause or causes, this theory may safely be neglected.

No. 4. The fourth theory of secular refrigeration can only account for the general cooling of the earth's mean temperature, and appears a very crude and on the whole unsatisfactory explanation of the phenomena now under consideration. For supposing that the earth was once in a state of igneous fusion, its crust must have become so far cooled before the carboniferous age that the internal heat

would be incapable of raising the temperature sufficiently to account for the tropical climate in high latitudes; and, as observed by Professor Dana, 'the same amount of change in the temperate and tropical zones would have rendered them uninhabitable by most plants and animals.' Moreover, this gradual cooling of the fused mass which, it is reasonable to suppose, must have ceased to exert any external influence of importance beyond local eruptions in the earliest ages of geological history, can under any circumstances only be applied to a lowering of the temperature, and in no way affords an explanation of returning warmth.

No. 5. The fifth theory, or the effect of ocean currents, commends itself for careful investigation. This agency was cursorily mentioned in the preceding chapter, as in a great measure influencing the local climate of the present day; and as its power is known to exist now, so there is every reason to believe it must have been very much the same throughout all ages, or at least since the surface of the globe has consisted of seas, continents, and islands.

There are several causes which generate oceanic currents, such as a wind constantly blowing in one direction, a lowering in the sea level of any particular part by evaporation and a consequent flow of water to re-establish equilibrium, or the discharge of any great river into the sea, which may preserve a sensible velocity for upwards of 500 miles from its mouth. But currents derived from such causes as these, although supplying interesting geographical studies, do not play a very important part in the consideration of climate. There are, however, two other causes which greatly modify the distribution of warmth over the whole globe. These are, the difference in temperature of the surface waters of the arctic or antarctic regions and the tropics, and the rotary motion of the globe. The action of the first is easily explained, if it be supposed that in the first instance the entire ocean is of one uniform average temperature and level: then as the water in the neighbourhood of the poles becomes more dense by the diminution of its temperature, and that about the equator becomes lighter under the influence of heat, the former will

by its greater weight raise the surface of the latter about its own level, and a surface current must result of the warmer water towards the poles, and consequently an inferior current of the cooler water towards the equator. Were the whole ocean of uniform depth and free from land, these surface currents would have in the northern hemisphere a north-easterly, and in the southern hemisphere a south-easterly direction ; the reverse being true for the inferior flow from the poles towards the equator. The deflections east and west are due to the angular velocity at the equator being in excess of that in higher latitudes. For instance, this former is about 1,000 miles an hour, whereas in latitudes 20°, 35°, and 40° it is about 940, 800, and 766 miles respectively, decreasing to nothing at the poles. Now, as the water will retain an eastern velocity greater than that due to the latitudes over which it passes, it would naturally have an apparent deflection towards the east. The present distribution of land and water, the influence of winds, and the water flowing from the poles sometimes being forced to the surface by opposing barriers, conspire

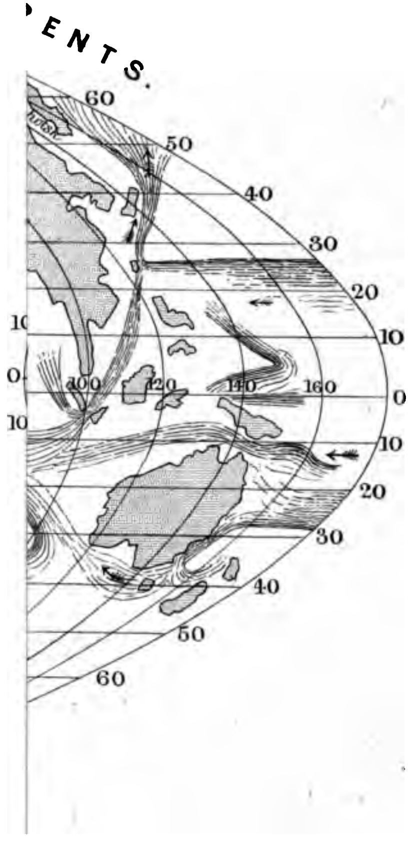
so to change the direction of these ocean streams as often to compel them to take a course directly opposite to that above mentioned. It is also an open question whether the great tidal waves do not exert a material influence on the marine currents, for it is a significant fact that the equatorial current flows from east to west. It is also believed to be capable of demonstration, that the general explanation of the origin and cause of direction of this equatorial current is open to objection, as being insufficient in itself alone to account for the phenomenon. The following taken from Mary Somerville's 'Physical Geography' is in accord with most works on this subject: 'When these currents leave the poles they flow towards the equator; but, before proceeding far, their motion is deflected by the diurnal rotation of the earth. At the poles they have no rotary motion; and although they gain it more and more in their progress to the equator, which revolves at the rate of 1,000 miles an hour, they arrive at the tropics before they have acquired the same velocity of rotation with the intertropical ocean. On that account they are left

behind, and consequently seem to flow in a direction contrary to the diurnal rotation of the earth. For that reason the whole surface of the ocean, for 30 degrees on each side of the equator, has an apparent tendency from east to west, which produces all the effects of a great current or stream flowing in that direction.' Now, from the nature of the case these polar waters must for the most part find their way to the tropics by an under passage, and would have every opportunity by friction with the inequalities of the ocean bed to acquire an angular velocity approaching to that due to the latitude; these colder and therefore heavier waters, too, must take a very considerable time to find their way to the surface. Moreover, a similar amount of water must pass from the tropics to the polar regions, and by the same reasoning a current would there be established with an opposite course, but with greater power, owing to the smaller amount of friction felt during their comparatively surface passage, and also owing to their more limited area due to the spheroidal shape of the globe. This, however, by the way; it little matters for the pre-

sent purpose from what source these marine currents originate, provided that their existence be admitted: and this is indisputable. The great equatorial current was first observed by Columbus, who says, 'It seems beyond doubt that the waters of the ocean move with the heavens.'

The most important marine currents are displayed in the accompanying chart, Fig. No. IV. The great masses of continent in the northern hemisphere offer enormous obstacles to the free circulation of the waters, the effect of which thereby becomes more intense in the connecting seas. With the exception of the Behring Strait, which is only 40 miles wide, the arctic and tropical seas are only connected at the north of the Atlantic; almost the entire north and south circulation, therefore, of this hemisphere has to be carried on through that ocean, the marine currents of which consequently become somewhat complicated, and the climatic effect concentrated into its neighbourhood. It has been estimated that the Gulf Stream conveys as much heat northwards as is received from the sun by 3,121,870 square miles at the equator. The climate of the

FIG. IV.



Stanford's Geog¹ Estab! 55, Charing Cross.

British Isles is about 12° warmer than that due to the latitude, and Mr. Croll has pointed out that the temperature of the whole hemisphere is raised by marine currents; and he observes that the 12° 'only represent the number of degrees that the mean and normal temperature of our island stands above what is called the normal temperature of the latitude.' By reference to the chart it may be noticed that the Gulf Stream is caused by the barrier of the Mexican coast and the Isthmus of Panama opposed to the flow of the equatorial current. Now, if this barrier were removed by the gradual subsidence of the land, the Gulf Stream, at least what is now understood by that term, would cease to exist, and the mean temperature of western Europe would be greatly lowered. If, on the other hand, the coast of Florida were united to Cuba and the configuration of the shore line somewhat modified, the course of this stream would be deflected more to the south, and if, at the same time, the lands of southern Europe and north-western Asia were reduced in elevation to a sufficient extent to afford a communication with the Pacific or even the Indian Ocean,

the islands thus formed would have a temperature higher and far more uniform than that now experienced in the same locality, the winter would be so moderated that the nights would never be cold, and even palms and tree-ferns might flourish. Improbable as such geographical changes may at first sight appear, they are, nevertheless, still quite within the bounds of possibility ; for the student of geology has constantly the unmistakable signs of changes far grander than these presented to his consideration. In Lyell's 'Principles of Geology,' after writing on the former geographical changes, it is stated that 'it is not too much to say that every spot which is now dry land has been sea at some former period, and every part of the space now covered by the deepest ocean has been land.'

No. 6. From what has been already said it will be observed that the marine current theory is intimately connected with the variations in the extent and elevation of land. The direction of any current may be so diverted from its course by the subsidence of existing portions of continents, or the rising of

the ocean bed, as to transfer its effect to a totally different part of the globe. Besides, however, the distribution of land plays an important part in the climate through the medium of the atmosphere. There is at the same time an analogy between these two agents; for as the solar rays are absorbed by the waters of the ocean, and their warmth carried to various portions of the globe by marine currents, so also the heat received by the surface of the soil is communicated by radiation to the air and distributed by the winds: in the former case the effect is more constant and is conveyed to distant regions by direct agency, but even then it cannot be felt, except in the temperature of the ocean itself, without the assistance of the atmosphere.

In considering this land theory perhaps the correct course to adopt would be to eliminate the marine currents, and in order to ascertain its bearing on climate to suppose the entire ocean to remain in a state of rest, with the exception of local waves and tides, whose waters would only have a temperature due to their latitude; but as new currents will be formed by new seas, and as a certain amount of

circulation must take place it appears preferable not to exclude these influential agents.

It is the property of soil to rapidly absorb the solar rays, and to again rapidly radiate their heat into space, this property varying to a great extent with the nature of the soil as regards its mineral constituents and vegetable covering. It is owing to these properties of absorption and radiation being displayed with greater energy by the solid than by the fluid portions of the globe that the climates found in the interior of large continents exhibit the extremes of heat and cold. As might be expected from the above, it is invariably found that the sea as compared with the contiguous land is colder during the day and warmer during the night: in other words, the temperature of the sea is more uniform than that of the dry land both during the day and night, and also during summer and winter; it is on this account that the expression 'insular climate' is employed in contradistinction to 'excessive climate.' This phenomenon was illustrated in the last chapter as applied to the present day, and as its influence is of no modern

creation, it only remains to point out how from a modified distribution of land a great change of climate would result.

It is not proposed to remodel the entire surface of the globe so as to obtain a maximum effect, but only to notice the result of some comparatively minor changes. On looking at a map of the world it may be seen that the point most remote from the oceanic influence occurs in the centre of Asia, about E. long. 100° and N. lat. 50°, close upon the line of permanent ground ice. Now if the tract of country to the east of the Obi river, and bounded on the south by the parallel of 55, were reduced below sea level, most remarkable climatic effects would be produced: and the depression necessary for this is nothing extraordinary, provided that sufficient time be allowed for its accomplishment. The general level of this region is less than 1,000 feet above the sea; it is true that at the eastern extremity there are the mountain ranges of Aldan and the Yablonoi, but their elevation is not great, the highest peak being only 4,263 feet above sea level, and the general height not exceeding 2,000

feet. Thus a sinking of say 2,500 feet would admit the waters of the Pacific, by way of the Okhotsk Sea, over this area, to unite with those of the Arctic Ocean. Moreover a branch stream would undoubtedly be diverted from the equatorial current, and the slopes of the Altai Mountains would be washed by its heat-bringing waters. The enormous change in the temperature of Central Asia that might thus be produced may be inferred from what has been already said. And if at the same time the Gulf Stream were driven more to the south, as previously mentioned, and communicated with this Siberian sea by way of the Mediterranean, Turkey, Black Sea, and the plains lying between the Caucasus and the Ural Mountains, the effect on the climate of Europe and Central and Northern Asia would be still further exaggerated. At present the winter in southern Siberia is long and severe; throughout January the mean temperature is 45° below zero, and during July, which comprises the brief summer, it does not rise above 68°; but on this being converted into a sea in the manner just described, all would be changed, the alternation of 113° of tempera-

ture would no longer exist, and the climate would resemble that of the Mediterranean; the isothermal line of 70°, which now passes from the east of the Mediterranean through Persia, Hindoo Koosh, Northern Tibet, and China, would take a more northerly course, and leaving Hindoo Koosh to the south would thence approximately follow the parallel of 45°; that is to say, Central Asia would have a mean temperature about 20 degrees warmer than at present, and a climate free from the great fluctuations of heat and cold now experienced in that region.

Passing now to the North American continent. Here the winters are severe and the spring is cold, the greatest extremes of temperature being found in the interior. Now, nearly the whole of the valley of the Mississippi, and the lake country extending to the Arctic Ocean, from Lake Winnipeg in the north-western direction, has an elevation of not more than 800 feet, and thus a connection might be established between the Arctic Ocean and the Gulf of Mexico without any very great depression. On this point it is stated in Ansted's 'Physical

Geography:' 'If, by a convulsive movement, or by a series of small alterations of level, the Gulf Stream should make its way through the valley of the Mississippi to the great lakes of Northern America—thus diverting a current of warm water that now crosses the Atlantic, and removing its great influence from European to American lands, —the result would be to diminish very considerably the average annual temperature of all parts of Europe, but chiefly to render the British Islands exceedingly less warm and somewhat less wet than they are at present. If, at the same time, the lands of Northern Europe, and the bottom of the Polar Sea adjacent to them, were elevated, the ice that now stops short of Norway might reach permanently as low as Scotland, and parts of Europe might be in the condition of Greenland and Labrador. An alteration so considerable might, and certainly would, occur were the comparatively small, but very possible, changes we have indicated carried out; and the greater part of the plants and animals that now flourish must either find fitter place in warmer lands to which

they could migrate, or be destroyed from the face of the earth.' It may be added, however, that supposing the Gulf Stream, or the greater part of it, to be diverted in the manner described, it is still possible that the climate of Europe might at the same time be preserved from the intense cold by being converted into an archipelago and warmed by the waters of the Indian Ocean passing from the Arabian Sea into the Caspian; the intervening country is certainly mountainous, but its elevation is most irregular, and the greater part, if not the whole, of the mountains is of volcanic origin.

Enough has now been said to give a general idea how the climate might be modified or entirely changed by a variation in the form and extent of land, and to show that changes of the earth's surface are followed as a consequence by changes of climate.

The remaining theories, which may be designated the astronomical theories, are dealt with in the following chapter.

CHAPTER V.

GREAT VARIATIONS OF CLIMATE AT DIFFERENT AGES—*continued.*

No. 7. That the shifting of the earth's axis, if it could possibly have taken place to a sufficient extent, might be made to account for phenomena of change of climate cannot be disputed. Although the possibility of such a change has been denied by many astronomers, there are some who maintain that it would be a necessary consequence to the oscillations of the earth's surface. But Newton, Laplace, and Airy have argued against the probability of this theory; and the latter has shown that the effect produced on the position of the axis by the elevation of mountain chains could not be appreciable, for their mass compared with the equatorial protuberance would be insignificant. To exemplify this by figures: suppose a mountain range 1,000 miles long, 100 miles broad, with a

continuous elevation of six miles, which is higher than any mountain now known, were placed on the 45th parallel, the direction of the range being due east and west; how might this be expected to make itself felt on the equilibrium of rotation? This may be answered with sufficient approximation as follows. The equatorial protuberance is 25,000 miles long, 6,000 miles broad, and 13 miles deep,

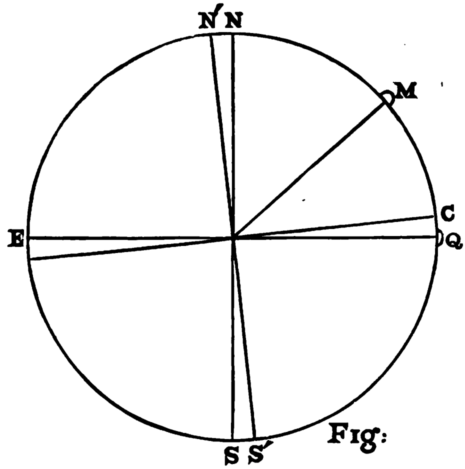


FIG.

i.e. it is a mass containing 1,950,000,000 cubic miles; and the mass of the mountain range above mentioned is 300,000 cubic miles: each of these

two masses may be supposed to be concentrated at the earth's surface, as in figure at Q and M, and their common centre of gravity would lie between them, as at C; and if the arc MQ be 16,000,000 feet in length, the distance CQ would be 2,460 feet, or less than half a mile: and this exaggerated case would give an angular displacement of only 25 seconds.

Any alteration in the position of the poles, even to the extent of three or four miles, would manifestly be insufficient to have more than a most trifling effect on the vicissitudes of climate which have passed over the earth's surface in past ages.

No. 8. Endeavours were made in the first and second chapters to give some idea of certain movements of the globe in its path round the sun which cause the power of the solar rays to be felt with varying intensity at different periods. It was also shown that the actual amount of heat received from the sun during the two seasons in which it is on either side of the equator must be equal, notwithstanding the difference in distance and

duration of action, each of these elements forming to the other a perfect counterbalance. And as by a similar reasoning it may be shown that the total amount of heat received by the entire globe is constant and does not vary with the excentricity of the orbit, it at first sight appears that these astronomical changes cannot be connected with variations of climate. It has, however, been observed by M. Adhémar, in his work entitled 'Révolution de la Mer,' that the climate does not so much depend on the quantity of heat received as on the quantity retained, that is, the difference between the amount received and the amount radiated into space: and he argues that as the total or sum of the nights during the period that the earth is in aphelion is less than when it is in perihelion, therefore the radiation in the former position is less than in the latter; and as the quantity of heat received is in each case the same, therefore the quantity retained in aphelion is greater than in perihelion. The seasons as now divided give 4,464 hours of day and 4,296 hours of night each year to the northern hemisphere, and 4,296 hours of day and 4,464

hours of night to the southern hemisphere. During the present cycle of the equinoxes this difference was greatest in the year 1248 A.D., and it will be least about the year 6498, the state of things being entirely reversed, in the year 11,748 ($= 1248 + \frac{21000}{2}$), the extremes being when the solstices occur at the earth's greatest and least distance from the sun.

According to this theory the glacial epoch should have been about 11,127 years ago, which does not give sufficient time for the great geological and geographical changes that have taken place, since that event. This insufficiency of time becomes more apparent by considering the geological strata which were formed, and the changes in the relative level of sea and land which took place, according to this theory, during the 10,500 years previous to the glacial epoch. Besides, the year 1248 A.D., or a date shortly subsequent to that time, should have been the period of greatest heat in the northern hemisphere, and tropical plants should then have flourished in Europe and North

America; and it is well known that no material change of climate in these regions has taken place since a time long previous to that date, and that tropical plants have not flourished there during historic times.

In searching, therefore, for an astronomical cause it becomes necessary to look for a phenomenon of less frequent occurrence; and this Mr. Croll has done by connecting the effect produced by the precession of the equinoxes with the variations in the excentricity of the earth's orbit. As the effect produced is dependent on the varying distance of the earth from the sun, it follows that any cause which will increase the limits of variation will augment the effect. It has been stated in the second chapter that the change of distance is now limited to less than three millions of miles, but that 200,000 years ago the range was more than three times as great, viz., 10¼ millions of miles. The following table constructed from calculations by Mr. Croll and Mr. Stone is given in Sir C. Lyell's 'Principles of Geology:'—

TABLE showing the variations in the excentricity of the earth's orbit for a million years before A.D. 1800, and some of the climatic effects of such variations.

	1	2	3	4	5	6
	Number of years before A.D. 1800	Excentricity of orbit	Difference of distance in millions of miles	Number of winter days in excess	Mean of hottest month in lat. of London	Mean of coldest month in lat. of London
D	1,000,000	·0151	2·75	7·3	83° F.	21° F.
	950,000	·0517	9·25	25·1	109°	3°
	900,000	·0102	1·25	4·9	80°	23°
C a	850,000	·0747	13·5	36·4	126°	—7°
C b	800,000	·0132	2·25	6·4	82°	22°
C c	750,000	·0575	10·5	27·8	113°	0°·6
	700,000	·0220	4	10·2	87°	17°
	650,000	·0226	4	11	88°	16°
	600,000	·0417	7·5	20·3	101°·9	7°·9
	550,000	·0166	3	8	84°	20°
	500,000	·0388	7	18·8	99°	9°
	450,000	·0308	5·5	15	94°	13°
	400,000	·0170	3	8·2	84°	20°
	350,000	·0195	3·5	9·5	86°	18°
	300,000	·0424	7·75	20·6	102°	7°
	250,000	·0258	4·5	12·5	90°	15°
B a	210,000	·0575	10·5	27·8	113°	0°·7
B b	200,000	·0567	10·25	27·7	113°	1°·9
	150,000	·0332	6	16·1	95°	12°
A	100,000	·0473	8·5	23	105°	5°
	50,000	·0131	2·25	6·3	82°	22°
	0,	·0168	3	8·1	84°	20°

EXPLANATION OF THE TABLE.

COLUMN 1. Division of a million years preceding 1800 into twenty equal parts.

COLUMN 2, computed by Mr. James Croll by aid of Leverrier's formula, gives the excentricity of the earth's orbit in parts of a unit equal to the mean distance or half the longer diameter of the ellipse.

COLUMN 3, which, together with the three following columns, has been computed by Mr. John Carrick Moore, gives in millions of miles the difference between the greatest and the least distances of the earth from the sun, during the excentricities given in column 2.

COLUMN 4 gives the number of days by which winter, occurring in aphelion, is longer than the summer in perihelion.

COLUMN 5 gives the mean temperature of the hottest summer month in the latitude of London when the summer occurs in perihelion.

COLUMN 6 gives the mean temperature of the coldest winter month in the latitude of London when the winter occurs in aphelion.[1]

[1] Supposing the mean temperature of the hottest and coldest months at London to be 64° F. and 38° F. respectively, and the temperature of space to be −239° F., the present excentricity being 0·0168, and the north winter occurring in perihelion; then the temperature (t) of the northern coldest winter month when in aphelion for eccentricity (e) will be found from this equation: $\frac{239+t}{239+38} = \left|\frac{0 \cdot 9832}{1+e}\right|^2$; and similarly, the temperature of the hottest northern summer month in perihelion from the formula $\frac{239+t}{239+64} = \left|\frac{1 \cdot 0168}{1-e}\right|^2$. Sir John Leslie and Mr. Traill give 64°·67, and Dove 63°·08 for the temperature of the hottest month in the latitude of London. The above results must be taken as mere rough approximations.

'A glance at this table will show that there are four periods in the course of the last million of years, namely, those marked A, B, C, D, in which there has been a large excentricity. For in A it was nearly three times as great as it is at present; in B three and a half times; in C we find two periods, one three and a half, and the other four and a half times as great, with an intervening smaller excentricity. If we could be sure that the greatest of these extremes Ca, in which the distance of miles was 13½ millions, was sufficient to produce glacial phenomena so much beyond those which the mere excess of polar land would occasion, we can hardly refuse to infer that the other distances, Cc, B, and A, although of subordinate magnitude, would have left to the geologist some recognisable proofs of their refrigerating influence. The periods of A and B would not, I conceive, be sufficiently distant from our era to afford time for that series of glacial and post-glacial events which we can prove to have happened since the period of the greatest cold. These events relate to changes in the level of the land in opposite directions, as well as to the excavation

of valleys, and variations in the range and distribution of aquatic and terrestrial animals, all of which take place at so slow a rate that 200,000 years would not be sufficient to allow of the series of changes with which we are acquainted. I agree, therefore, with Mr. Croll, that if the date of the most intense glacial cold can be arrived at by aid of a very large excentricity, it would be a more probable conjecture to assign C than B as the period in question.'*

Sir John Lubbock differs from this conclusion, and prefers to assign the glacial era to the periods A and B, and Mr. Croll has expressed a similar opinion. It is not the intention, however, here so much to fix exact dates as to study the cause and effect. What climate, then, might be expected with an excentricity of ·0567, when the distance varies by 10¼ millions of miles, the earth being 86,553,000 miles, and 96,803,000 miles distant from the sun in perihelion and aphelion respectively? Owing to the precession of the equinoxes both the northern and southern hemispheres must have ex-

* Sir C. Lyell.

perienced winter and summer under these conditions. Suppose, then, that the northern summer occurred when the earth was in perihelion, that is when the earth was $10\frac{1}{2}$ millions of miles nearer the sun than in winter. Under these circumstances the summer would be very much shorter than at present, and at the same time, cæteris paribus, very much hotter, whereas the winter would be much longer, and considerably more severe. In the southern hemisphere, on the other hand, the summer would be longer, and the winter shorter, both being more moderate; extremes of heat and cold would there be unknown. The temperature of the northern winter, being reduced about one-ninth, would bring the isocheimal line of 32° F. to the south of Europe, and all the rain which now falls during that season to the north of this line would come down in the form of snow; and the winter would not only be increased in intensity, but also be of longer duration, the period between the autumnal and vernal equinoxes being fourteen days longer than at present, that is, the winter would be more than one-thirteenth longer. With this state of

things the greater part of the northern hemisphere would during the cold season be covered with snow of a considerable depth, and unless the heat of the short summer should be sufficient to dissipate the covering, the depth of snow would be each year accumulative, and after a sufficient accumulation a glacial epoch must result. It is true that the power of the solar rays would be augmented by the proximity of the sun during summer; but it does not follow that their power would be felt with greater or even equal effect at the earth's surface, for the chilliness of the atmosphere due to the snow-clad hills and ice-bound soil would be most favourable for the formation of mist and fogs, and the air would, at all events, be heavily charged with vapour, which would intercept a great number of the sun's rays, and so in all probability prevent the melting of the entire mass of snow.

It has been stated by Professor Tyndall that 'the thing most needed to produce the glaciers is an *improved condenser*; we need, if anything, more vapour, but we need a condenser so powerful that this vapour, instead of falling in liquid showers to

the earth, shall be so far reduced in temperature as to descend in snow.' Now this is exactly what results from the increased excentricity of the orbit; the winter occurring in aphelion, the northern hemisphere becomes an improved condenser to be supplied with more vapour from the southern seas during the increased length of the southern summer.

If, as according to this theory, the exaggerated excentricity of the earth's orbit considerably affects the climate in the manner described, it is evident that during the period in which the excentricity was large there should have been a change of climate every 10,500 years, the glacial epoch, alternating between the northern and the southern hemispheres, occurring in each when its cold season was in aphelion. This would account for the vicissitudes of temperature which have been noticed by geologists as taking place at comparatively short intervals. These are referred to in the quotation from Sir Charles Lyell in Chapter IV.: 'The cold which had gone on increasing . . . . . . though not perhaps without some oscillations of temperature.' Again, in speaking of the interglacial periods, Sir

C. Lyell says: 'M. Morlot and others have adduced abundant evidence of two glacial periods in the Alps, during the first of which the glaciers attained colossal dimensions, filling the great valley of Switzerland with ice, which reached from the Alps to the Jura, while on the other side of the great chain other contemporaneous glaciers invaded the plains of the Po, where they have left moraines of truly gigantic dimensions. After these huge glaciers had retreated for a time they advanced again, but on a smaller scale, though still vastly exceeding in size the largest Swiss glaciers of our day. The interval of milder weather, marked by the decrease of snow and ice in the Alps, has been called by Professor Heer the Interglacial Period, which must have been of considerable duration, for it gave time for the accumulation of dense beds of lignite, like those at Dürnten and other localities near Zürich. During this intercalated series of warmer seasons the climate is supposed by Heer to have closely resembled that now experienced in Switzerland.'

As a well-defined period during which the cli-

mate was free from intense cold, and in some respects of a tropical nature, the carboniferous age may be taken. It is believed that geologists generally agree that the climate of this period was temperate and moist, free from extremes of heat and cold, in fact of a moist insular character, such as would be most conducive to the vegetation of a particular kind.

If the temperature of the ocean be deduced from animal life, the Lithostrotion basaltiforme, which is common in the carboniferous formations of both Europe and the United States, amongst others, proves that the waters were at no part of the year below 66° F.

The coal beds give sufficient evidence of profuse vegetation; and the vegetation contains internal signs of a moist insular climate; for instance, the equiseta, lepidodendra (kin to the living lycopodia), and ferns in general which abound in the coal measures, could only flourish exuberantly in a warm and humid atmosphere. That the climate was not truly tropical may be inferred from the fact of the formation of coal. Under a clear tropical sun the dead vegetation must have been quickly decom-

posed. At the present day nothing answering to the peat of the temperate regions is found in the tropics. The climate now most suited to the formation of peat appears to be that of the Falkland Islands. In Darwin's 'Journal of Researches' he says: 'In these islands almost every kind of plant, even the coarse grass which covers the whole surface of the land, becomes converted into this substance.'

As above stated, such must have been the climate of the southern hemisphere when the northern summer occurred in perihelion, the excentricity of the orbit being a maximum or nearly so. By changing the order and making the northern summer contemporary with the aphelion position of the earth, the climate of that hemisphere would become such as is believed to have existed in the carboniferous age.

In considering this question it is of the greatest importance to bear in mind that heat alone can no more be made to account for the formation of coal, than can cold alone be held accountable for the growth of glaciers. The gigantic coniferæ and treeferns of the carboniferous strata do not so much imply tropical heat as a humid atmosphere of moderate and equable temperature.

CHAPTER VI.

CONCLUDING REMARKS.

Of all the theories which have been advanced to account for the past changes of climate, those which appear deserving of the greatest consideration are, that dependent on the varied distribution of land and water, with the consequent variation of ocean currents, and that derived from the precession of the equinoxes and the excentricity of the earth's orbit. Sir Charles Lyell was undoubtedly in favour of assigning the first importance to the distribution of land and water, and supposed that the glacial epoch might be accounted for by the massing of all the land round the poles, the tropical and adjoining regions being occupied by the ocean; and that the climate of the carboniferous age was due, on the other hand, to the collection of the land about the equator, the polar regions being open sea.[1] Were

[1] Lyell's 'Principles of Geology,' vol. i., chap. xii.

the earth's surface remodelled after this fashion, it is indisputable that the climatic effect would be in the assumed direction, but no signs of changes sufficiently comprehensive have been pointed out, and such a distribution of land and sea at least appears unlikely. This theory may be perfectly safe as regards its possibility, but the probability of its correctness is not so certain; for it must be borne in mind that the origin of a regular succession of warmer and colder climates has to be explained.

The earth's life, so to speak, may be divided into days, years, and longer periods of greater warmth and cold. The day commences with the comparatively cold morning, and as the sun rises and continues to exert its influence the temperature gradually increases until it arrives at a maximum about or soon after noon, and then, the warmth decreasing, the day passes into the colder night at sunset. The year commences with the winter solstice, and as the sun apparently advances in its orbit, the temperature of the northern hemisphere gradually increases until

it attains a maximum at or about the summer solstice, and again decreases as the earth proceeds on its way to the autumnal equinox and on to the winter solstice. Thus the temperature of each hour, day, and season is in the main attributable to one and the same cause, viz., the relation of the earth to the sun, although considerably modified by other causes, such as have been mentioned in the foregoing chapters. Why, then, should not the climate of the longer periods be derivable from the same source and attributed to the varying excentricity of the earth's orbit? No distribution of land and water, nor any arrangement of marine currents can hinder the succession of the seasons, nor make the summer of one hemisphere colder than the winter of the other, notwithstanding that they may have a modifying effect. No earthly contrivance can alter the general influence of the sun, and it therefore certainly appears more reasonable to search for the cause of the great vicissitudes of climate among cosmical phenomena of regular recurrence than among mundane configurations.

The summer of the northern hemisphere now

occurs in the aphelion position of the earth, and, therefore, according to this astronomical theory, the temperature of that region should be in excess of that of the southern hemisphere. Such is the case, the mean annual temperatures being 60° F. and 56½° F. The excentricity is nearly at a minimum, and therefore a great difference could not be expected; moreover, a portion of this difference may be assigned to other causes, but it is impossible to say exactly how much. This fact is not brought forward as a proof of the theory, but merely as an argument in its favour.

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